北海道サロマ湖のアイスアルジーのキサントフィル色素と最大量子収率(F_v/F_m)の変動

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Variability in Xanthophyll Pigments and Maximum Quantum Yield (F_v/F_m) of Ice Algae in Saroma-Ko Lagoon, Hokkaido

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Introduction

Light through the sea ice is much reduced due to light reflection by snow cover, sea ice, and brine channels utilized as fundamental habitats by phytoplankton called ice algae (Arrigo et al. 1991). Ice algae can grow to an extremely high biomass at the bottom surface layer by acclimating to low irradiance in the brine channels. Because of the low light intensity, light utilization could be the most important factor on growth of ice algae. The pigments composition, biomass, and the photosynthetic characteristics of ice algae can be highly variable due to the different ambient irradiance level at the algal habitats as well.

The analysis of pigment composition, especially variation of xanthophyll pigments such as diatoxanthin (DT) known as a photoprotective pigment and diadinoxanthin (DD) known as a photosynthetic pigment is one of the indexes indicating photosynthetic response to irradiance in phytoplankton as well as ice algae. DD converts into DT due to de-epoxidation under light condition, and DT plays a role to protect phytoplankton from photoinhibition. The DD+DT/Chlorophyll *a* ratio and DT/DD+DT ratio (DES) indicate pool size of xanthophyll cycle and activity of photoprotective of phytoplankton, respectively. Maximum quantum yield (F_v/F_m) of photosystem II (PSII) is one of the photosynthetic characteristics and indicates potential of photosynthetic capacity.

The objective of the present study is to examine the variability in pigments composition and maximum quantum yield (F_v/F_m) of photosystem II (PSII) of ice algae due to irradiance, caused by physical factors such as snow cover, sea ice, and brine channels in Saroma-Ko Lagoon, Hokkaido, Japan.

Materials and Methods

Samplings were conducted on March 5, 2010 and March 10, 2011 at the station off Sakae-Ura in Saroma-Ko Lagoon (44 ^{o}N, 143 ^{o}E). A whole ice core was taken by a CRREL core samplar at the four corners (St. 1, 2, 3, and 4) of 1 m^2 surface area. Each ice core was cut every 3 cm from the bottom surface of ice core to 9 cm long and named bottom, middle, and top, respectively. Sliced ice core subsamples were melted in the filtered sea water under dark condition. Photosynthetically active radiation (PAR) in the air and at the undersurface of the sea ice, temperature, thickness of snow cover and ice cores, and salinity at three ice layers were measured as the environmental factors. Average extinction coefficient (k) was calculated from a formula (1) (Aota and Ishikawa 1982) :

$$k = 1 / D \times \ln [PAR_0 (1 - r) / PAR_z] \qquad \cdots (1)$$

where D is ice core length, PAR_0 is PAR in the air, PAR_z is PAR at the undersurface of the sea ice, and r is albedo estimated for sea ice in the present location as 0.8. Subsamples for pigment analysis were filtered onto Whatman glass fiber filters (GF/F) and frozen by liquid nitrogen and stored at -60 ^{o}C immediately. The pigments were extracted in N,N-Dimethylformamide (DMF) (Suzuki and Ishimaru, 1990). All processes of pigment analysis were conducted under dark condition. Species were also identified under the microscope. Pigment packaging index (the absorption efficiency, Q_a*) was calculated as a formula (2) (Bricaud et al. 1995) :

$$Q_a^* = a_{ph} (675) / (Chl\ a \times 0.027) \qquad \cdots (2)$$

where a_{ph} is the absorption by phytoplankton at 675nm, Chl *a* is the Chl *a* concentration, and 0.027 is the specific absorption coefficient of Chl *a*. Maximum quantum yield (F_v/F_m) of photosystem II (PSII) at each ice layer was measured by a chlorophyll fluorometer (Water-Pam, Germany) within an hour from the collection immediately after dark adaptation at 0 ^{o}C for 30 minutes in a dark laboratory. A measuring light detects the minimum fluorescence (F_0) in the dark-adapted state. When F_0 had become stable, a saturating pulse was supplied. A saturating pulse detects the maximum fluorescence (F_m). A ratio of F_v

to F_m of PSII (maximum quantum yield) was calculated from a formula (3) (Bulter and Kitajima 1975) :

$$F_v/F_m = (F_m - F_0) / F_m \qquad \cdots(3).$$

Results and Discussions

The PAR at the undersurface of the sea ice of the surface value was 2.48% in 2010 and 1.08% in 2011. Thickness of snow cover in 2010 and 2011 was similar, which was 11.9cm and 11.1cm, respectively. Average ice core length in 2010 and 2011 was 43.7cm and 51.6cm, respectively. In Saroma-Ko Lagoon, thickness of the seasonal sea ice can be about 40 cm, so the sea ice in both years was probably well-developed.

The occurrence of chlorophyll a (Chl a), chlorophyll c (Chl c), fucoxanthin, DD, DT, and β-carotene in two years indicates that dominant species in the sea ice collected for this study were diatoms such as *Odontella aurita*, *Detonula confervacea*, and *Thalassiosira* spp. which were confirmed by microscope identification.

Chlorophyll a concentration was mostly highest at the bottom surface layer in sea ice in both years. Average Chl a concentration at each layer of sea ice among four stations in 2011 was more than 10 times higher than that in 2010. The absorption efficiency (Q_a*) in 2010 was about eighty times higher than that in 2011. This indicates ice algae in 2010 have lower package effect compared with that in 2011. As for DD+DT/Chl a ratio and DES, the highest values were mostly observed at the top layer of sea ice among four stations in both years (Fig. 1), and there was a big difference among layers in 2010. This result suggests that ice algae in 2010 can activate of xanthophyll cycle to acclimate to the ambient light intensity more than ice algae in 2011. The DD+DT/Chl a ratio and DES at each ice layer in 2010 were more than twice and three times higher than that in 2011, respectively. These results suggest that photoprotective activity of ice algae in 2010 was more enhanced than those in 2011. The average extinction coefficient (k) of the sea ice in 2010 and 2011 was 0.048 cm^{-1} and 0.057cm^{-1}, respectively. This result indicates that the rate of attenuation through sea ice in 2011 is higher than in 2010. Therefore, ice algae collected in 2011 may be exposed lower light intensity compared with ice algae collected in 2010 because of longer ice core or higher package effect.

The maximum quantum yield, F_v/F_m showed the maximum at the bottom surface of sea ice in both years, and F_v/F_m at each ice layer in 2011 was higher than those in 2010 (Fig. 2). This observation may suggest that the potential efficiency of electron transport in PSII was higher in 2011 than 2010. This might be caused by photoinhibition in PSII, damaging PSII.

In conclusion, whereas large size pool of xanthophyll cycle and high photoprotective activity could be caused by the decrease of ice core thickness and low package effect, increasing the light penetration in the sea ice and photoinhibition to ice algae, the photoinhibition may cause decrease the potential of photosynthetic capacity of ice algae.
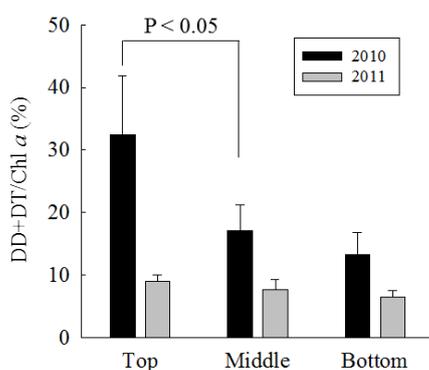
Fig 1. Average DD+DT/Chl a ratio at each ice layer collected from station 1, 2, 3, and 4 in 2010 and 2011.
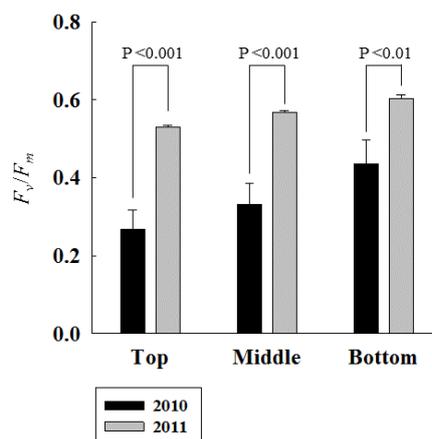
Fig 2. Average F_v/F_m at each ice layer collected from station 1, 2, 3, and 4 in 2010 and 2011.

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